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NATIONAL BUREAU OF STANDARDS REPORT

9992

REPORT ON THE PERFORMANCE OF ASBESTOS FIBER-BASE BUILT-UP ROOFS

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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REPORT ON THE PERFORMANCE OF ASBESTOS FIBER-BASE BUILT-UP ROOFS

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Sponsored by

Office of the Chief of Engineers, U. S. Army
Directorate of Civil Engineering, U. S. Air Force
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Report on the Performance of Asbestos Fiber-Base Built-Up Roofs

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Contents

Report on the Performance of Asbestos Fiber-Base Built-Up Roofs

1. Introduction

The built-up membrane has three basic components, felts, bitumen, and a surfacing of bitumen with or without aggregate. It forms a semi-flexible weatherproof covering made with as little as two or as many as five plies of felt, custom-built to fit the contours of the deck. The felt reinforcement is either organic (felted papers, rags and shredded wood fibers) or inorganic (asbestos or glass fibers). It has been the practice in roofing industry to specify the number of plies used in a built-up roof according to the service life desired, for example:

10 years for 2 felts and 3 layers of bitumen

15 years for 3 felts and 4 layers of bitumen

20 years for 4 felts and 5 layers of bitumen

Some construction agencies of the United States Government permit the substitution of asbestos or glass base felts for organic felts on a ply-for-ply basis. However, the substitution of glass felts on a one-ply-less basis is permitted in some cases as a result of information developed during an NBS field survey as reported in NBS Report 6966 [1] 1/. Because of the interest in establishing a criteria for selection of the number of plies of any given felt and because of

1/ Numbers in brackets indicate literature reference at the end of this report.

the request of a manufacturer of asbestos felt that such a felt be specified on a ply-for-ply basis with glass felt and one-ply-less basis with rag felt, the National Bureau of Standards was asked to study the performance of asbestos base built-up roofs as part of the Tri-Service Building Investigation Program.

Section 4 of this report states the conclusions which have been drawn as a result of this study. Sections 2 and 3 describe in detail the field and laboratory phases of the study.

2. Field Survey

The purpose of the field survey was to evaluate the performance of asbestos felt built-up roofs. Many factors other than the type of reinforcing membrane must be considered in evaluating the performance of a built-up roof. Failures may occur that are in no way related to the materials used in a roof membrane. Premature roof failures generally result from workmanship rather than from faulty materials.

2.1 Selection and Inspection of Roofs

The Johns-Manville Corporation submitted a list of 44 asbestos-felt built-up roofs for consideration. This list contained information on age, membrane construction and substrate conditions for each roof. Twenty-three of these roofs were selected for evaluation. Three roofs suggested by Mr. S. L. Howell, located at the Norfolk Naval Base, were also included for evaluation.

This report gives the results of field studies of 26 asbestos felt built-up roofs carried on in 1968 (see Table I). The field studies included roof inspections in 9 cities as follows:

	No. of Roof Inspections
Raleigh, North Carolina	1
Durham, North Carolina	1
High Point, North Carolina	3
Winston Salem, North Carolina	2
Norfolk, Virginia	3
Philadelphia, Pennsylvania	5
Trenton, New Jersey	1
Green Bay, Wisconsin	6
Wisconsin Rapids, Wisconsin	4

The results of laboratory investigations on cut-outs taken from the above roofs are also included in this report (see Section 3).

TABLE I

LOCATION AND INFORMATION ON DECK CONSTRUCTION

Roof No.	Age	Location	Bldg. Type	Area	Deck		Insulation	
					Type	Slope	Type	Thick
	yrs.			$ft.^2$		in/ft.		in.
1	13	Raleigh, N.C.	Office	10,000	Concrete	0	Foam-glass	1
2	17	Durham, N.C.	Gymnasium	29,000	Precast Concrete	4	Fiber-glass	1
3	18	High Point, N.C.	Gymnasium	10,500	Wood	Barrel	None	
4	18	High Point, N.C.	Auto Show Room	10,000	Wood	3	None	
5	18	High Point, N.C.	Auto Machine Shop	54,000	Wood	3	None	
6	31	Winston-Salem, N.C.	Gymnasium	10,000	Wood	Barrel	None	
7	6	Winston-Salem,N.C.	Warehouse	12,700	Wood	1/2	None	
8	17	Phila.,Pa.	Kiln	13,800	Precast Concrete	3/4	None	
9	13	Phila.,Pa.	Shed	5,200	Concrete	1/2	None	
10	18	Phila.,Pa.	Factory	7,800	Wood	1/2	None	
11	13	Phila.,Pa.	Office	13,500	*Coal-Tar Roof	3/4	None	
11b	13+	Phila.,Pa.	Office	13,500	Concrete	3/4	None	
12	16	Phila.,Pa.	Dept.Store	11,200	Precast Gypsum	4	None	
13	11	Trenton,N.J.	Factory	40,000	Precast Concrete	0	Wood Fiber	1

* Roof No. 11 placed over existing coal-tar roof No. 11b.

continued

TABLE I - continued

Roof No.	Age	Location	Bldg. Type	Area	Deck		Insulation	
					Type	Slope	Type	Thick
	yrs.			$ft.^2$		in/ft.		in.
14	9	Green Bay, Wisc.	Factory	7,200	Wood	1/2	None	
14b	42	Green Bay, Wisc.	Factory	5,000	Wood	1/2	None	
15	15	Green Bay, Wisc.	Factory	6,700	Steel	0	Wood Fiber	1
16	29	Green Bay, Wisc.	School	12,500	Wood	0	Wood Fiber	1
17	6	Wisconsin-Rapids, Wis.	Factory	7,700	Concrete	1/4	Wood Fiber	1
18	12	Wisconsin-Rapids, Wis.	Factory	23,600	Concrete	1/4	Wood Fiber	1
19	11	Wisconsin-Rapids, Wis.	Factory	11,700	Concrete	1/4	Wood Fiber	2
20	12	Wisconsin-Rapids, Wis.	Factory	10,000	Wood	1/4	Wood Fiber	2
21	18	Green Bay, Wis.	Factory	22,800	Steel	1/2	Wood Fiber	1
22	13	Green Bay, Wis.	Office	7,500	Wood	1/2	Wood Fiber	1/2
23	10	Norfolk, Va.	Hanger	100,000	Concrete	Barrel	Wood Fiber	1-1/2**
24	15	Norfolk, Va.	Aircraft Machine Shop	60,000	Concrete	Barrel	None	
25	15	Norfolk, Va.	Warehouse	50,000	Steel	4	Wood Fiber	1

** Double layer of 3/4-inch wood fiber insulation

Roof inspections were made in company with representatives of the manufacturer (with the exception of the military installations) and frequently with the owner or manager of the building. The local roofing contractor was contacted for type and history of repairs whenever possible. Copies of bond documents and inspection sheets were obtained in many cases.

A roof inspection form was developed and used for the evaluation of each roof. A copy of this form is presented in Figure 1.

A 1-foot by 3-foot cut-out specimen from all but a few of the roofs were obtained for laboratory examination. The areas from which the cut-outs were made were selected by the National Bureau of Standards observers. A local roofing contractor made the cut-outs which were then shipped to the National Bureau of Standards. The results of these laboratory examinations are reported in Section 3.

2.2 Results

The roofs selected for examination were applied to many types of roof decks on slopes ranging from dead-level to barrel. The inspection included roof membranes on both insulated and non-insulated decks.

Asbestos felts encountered during the investigation were made of asbestos mineral fibers and saturated with bitumen and met the following specifications:

Product	100 sq.ft. per Roll	Approx. Weight per Roll lbs.	Applicable Specifications Federal	ASTM	Navy
No. 45 Asbestos Base Felt	1	43	-	-	-
No. 15 Asbestos Finishing Felt	4	60	HH-R-590, Class A Type I Perforated Type II Unperforated (23 June 1964)	D-250-60	NAVFAC Spec. 7YK AA15 (1 Nov. 1966)

Roofs examined were smooth surface, 2- 3- and 4-ply asphalt-saturated asbestos felts with two exceptions. Roof Nos. 1 and 15 were coal-tar-saturated asbestos felt with roof No. 1 having a gravel surface.

Figure 1.
ROOF INSPECTION CHECK LIST

1. Building ______________ 2. Location ______________

3. Year applied ______________ 4. Manuf. & Spec. ______________

5. Deck ______________ 6. Slope ______________

7. Insulation ______________ 8. Surfacing ______________

9. Bonded ______________ 10. Roof area ______________

11. Other Remarks ______________________________

GENERAL

1. Appearance ______________ 2. Water tightness ______________

3. Repaired areas ______________ 4. Other ______________

FELTS

1. Blisters ______________ 2. Cracks ______________

3. Fismouths ______________ 4. Buckled ______________

5. Edges curled ______________ 6. Delaminations ______________

7. Condition of exposed felts ______________________________

8. Condition at flashings ______________________________

9. Condition at bends ______________________________

10. Other observations ______________________________

BITUMEN

1. Top pouring or surfacing ______________________________

2. Between plies ______________________________

3. Water standing or dry ______________________________

4. Alligatoring, cracking, etc. ______________________________

5. Water-soluble products ______________________________

6. Condition ______________________________

7. Other observations ______________________________

2.2.1 Membrane Appearance

1. Small blisters, indicating lack of interply adhesion, was a predominant characteristic of many of these roofs.

2. The roofs inspected seemed to be well maintained. Alligatoring on thick or uneven coatings was prevalent on many of these roofs.

3. The rate of deterioration of the smooth bituminous coatings appeared to reach its peak with the exposure of the asbestos fibers of the felt.

2.2.2 General Observations

1. Conversations with building owners indicated that leakage was not a problem and the owners appeared satisfied with the performance of their roofs.

2. The roof inspections were completed during, or shortly after, periods of inclement weather. The majority of low slope or dead-level roofs exhibited ponding problems. Several factors were responsible for these conditions; improperly placed drains, clogged drains, and improper attention to structural detail.

3. Although not directly related to our task, it was observed that the flashing details and their performance was good.

3. Laboratory Study

Laboratory investigations were carried out on the cut-outs taken from the roofs inspected. Physical tests such as breaking load, elongation, and linear thermal expansion of specimens prepared from the roof cut-outs were performed. (The results were compared with similar specimens prepared with organic and inorganic-base roofing membranes previously reported [3] and [4].) In addition the cut-outs were examined for composition, condition of bitumen between plies, thickness of bitumen between plies and weight.

3.1 Physical Properties

Dumbbell-shaped specimens were cut from each roof cut-out. Five specimens were cut in each direction (longitudinal and transverse to felt machine direction) to provide triplicate determinations of load-strain properties and duplicate determinations for linear thermal expansion measurements. The load-strain properties of the specimens were determined at 0°F using a universal testing machine equipped with a controlled temperature chamber. The gage length for strain calculations was defined as the distance between the jaws of the testing machine and was 4.5 inches. A straining rate of 0.05 inch per minute (1.1% per minute) was used in each determination. Table II lists the laboratory results for breaking load and elongation modulus. (Also see Appendix I).

For linear thermal expansion measurements the dumbbell-shaped built-up roof specimens were fitted with gage points to receive a 5-inch Whittemore gage. The specimens were placed in a conditioned

chamber and initial length measurements made at a temperature of 30°F. The chamber temperature was lowered to -30°F and measurements were again made. The linear thermal expansion coefficients were calculated from the change in length due to the 60°F change in temperature and are reported in Table II.

3.2 Composition

A two-inch by three-foot strip was cut from each roof cut-out, and cooled to approximately -30°F. While still cold the plies of the membranes were separated, counted and the between-ply bond areas examined. The number and type of plies for each roof membrane cut-out is given in Table III. The condition of the between-ply bonding is noted in Table IV.

The between-ply thickness was measured with a tool maker's microscope that has a movable stage driven by a micrometer screw. The between-ply spreading rates were calculated from the thickness measurements using a value of one for specific gravity of the asphalt. The between-ply spreading rates, in pounds per 100 square feet, are listed in Table III.

The weight of a 6- by 6-inch specimen taken from each roof cut-out was measured to the nearest tenth of a gram after conditioning for 72 hours at 73°F and 50% RH. The weight of a number of membranes, in pounds per 100 square feet, is also listed in Table III.

3.3 Results

The results of the engineering properties and the physical characteristics of the asbestos roof membranes are listed in Tables II and III.

TABLE II

ENGINEERING PROPERTIES

Roof No.	Felt Direction	S Breaking Load 1/	M Elongation Modulus 1/	α Coef. Of. Thermal Expansion 2/	Thermal Shock Resistance Factor 3/
		lbs/in	lbs/in	deg. F $^{-1}$	deg. F
1	Longitudinal	550	8.9 x 10^4	10.6 x 10^{-6}	590
	Transverse	220	4.8	20.8	220
2	L	340	4.7	not attainable	
	T	150	2.9		
3		No cut-outs taken			
4	L	380	4.6	6.8	1200
	T	300	3.7	21.1	380
5	L	290	3.9	10.2	730
	T	130	2.6	27.1	180
6		No cut-outs taken			
7	L	320	3.7	14.9	580
	T	190	3.0	38.1	160
8	L	250	3.8	9.3	710
	T	140	2.9	22.3	210
9	L	350	4.1	12.0	720
	T	160	2.6	25.0	250
10	L	250	3.0	25.5	330
	T	90	1.3	6.7	100
11	L	190	2.5	11.2	660
	T	60	1.0	25.2	250
11b	L	390	5.9	17.3	380
	T	240	4.8	27.0	190
12		No cut-outs taken			
13	L	590	6.6	4.7	1910
	T	240	4.1	16.8	350
14	L	410	4.8	6.5	1330
	T	210	3.9	26.3	200

TABLE II - continued

Roof No.	Direction	S Breaking Load 1/	M Elongation Modulus 1/	α Coef. Of Thermal Expansion 2/	Thermal Shock Resistance Factor 3/
		lbs/in	lbs/in	deg. F^{-1}	deg. F
15	L	780	10.7	6.4	1110
	T	290	7.2	14.3	290
16	L	410	4.4	4.4	2160
	T	150	3.0	31.5	150
17	L	240	3.2	18.7	390
	T	120	2.4	26.3	200
18	L	290	4.2	4.6	1520
	T	150	3.2	20.2	220
19	L	340	5.0	11.0	610
	T	200	3.9	28.5	180
20	L	350	5.0	1.3	4970
	T	160	3.3	26.2	190
21	L	380	5.3	25.2	290
	T	150	3.0	40.0	120
22	L	440	6.1	8.2	890
	T	170	3.7	26.8	180
23	L	280	4.1	9.8	700
	T	110	2.3	20.2	250
25	L	370	5.3	8.5	820
	T	140	2.8	34.9	140

1/ at 0°F

2/ Temperature range +30°F to -30°F

3/ $TSRF = \frac{S}{M \alpha}$

TABLE III

PHYSICAL CHARACTERISTICS OF THE ASBESTOS ROOF MEMBRANES

Roof No.	Number of Plies	Calculated Membrane Weight 1/ lbs/100 sq.ft.	Between-Ply Bituminous Spreading Rate lbs/100 sq.ft.
1	3	119	5
2	4	147	11
4	4 2/	110	13
5	4	137	11
7	3 2/	142	15
8	3 2/	3/	19
9	3 2/	140	18
10	4 2/	173	3/
11	3	102	17
11b	3	3/	3/
13	4	137	10
14	2	123	17
15	4	177	3/
16	4	148	11
17	2	124	13
18	2	180	18
19	2	111	17
20	2	130	17
21	4	213	18
22	4	164	17
23	4	3/	3/
25	4	3/	3/

1/ Weight, including top coating.

2/ Including rag-felt base sheet

3/ Condition of membrane not satisfactory for measurement

4. Summary and Conclusions

4.1 Field Studies

1. Generally the examination made of 26 3- and 4-ply asbestos-felt built-up roofs from 6 to 42 years of age and with a mean age of 15 years indicated that satisfactory performance was obtained from this type of roof.

2. Most problems observed could be attributed to improperly designed membrane sub-structures, moisture from beneath the roof membrane, or inadequate placement of bitumen between the plies.

3. On several roofs the top surface was completely weathered off, exposing the white asbestos fibers, but in no case did the observations made in the field or laboratory examinations show any further signs of felt deterioration. The poor appearance of the smooth surface coating materials after 10 years of service prompted many building owners to recoat.

4. There was no evidence to indicate differences in performance based on regional climatic conditions.

5. Roof membranes with 1/4-inch per foot or greater slope with good drainage performed better than roofs with poor drainage.

4.2 Laboratory Studies

1. In four of the 26 roof cut-outs the laboratory analysis revealed major departures from manufacturer's specification in regards to membrane construction.

2. The between-ply spreading rate determined in the laboratory was less than the manufacturer's specified application of 20 lbs. per 100 sq. ft.

3. Between-ply blistering appeared either to be caused by inadequate application of bitumen or moisture conditions prevalent at time of construction of membrane. Most membranes exhibited excellent interply adhesion.

4. In several cases the entire membrane was separated from the deck. This was attributed to moisture from beneath the deck and in one case (Roof No. 11) incompatibility between an asphalt roof placed over an existing coal-tar roof.

TABLE IV

COMMENTS

Roof No.	Age Yrs.	By Building Owner	Roof Inspection at Site - 1968	Laboratory Inspection of Cut-Outs
1	13	Excellent service	Well constructed, Excellent appearance	Excellent workmanship, No deterioration noted
2	17	Minor repairs needed	Coating worn, Felt exposed, Felt delaminated (see Fig. 2)	Good workmanship, No deterioration noted
3	18	No leaks	Separation between deck & membrane, blisters.	
4	18	No leaks	Fair appearance, Numerous blisters (see Fig. 3)	Interply loss of adhesion approx. 50% (see Fig. 4)
5	18	No leaks	Fair appearance	Good workmanship
6	31	Excellent service	Well constructed, Excellent appearance	
7	6	Minor repairs needed on top surface	Fair appearance, Poor application of top coating	Excellent bond between plies
8	17	Excellent service	Good appearance	Excellent bond between plies
9	13	Severe leaks, some repairs made	Badly blistered, Top surface cracked & alligatored (see Fig. 5)	Poor adhesion between plies, Similar to roof No. 4
10	18	Minor leaks, Some repairs made	Separation of T&G wood deck caused splits in roof membrane	Poor adhesion between plies, Similar to roof No. 4
11	13	No leaks	Large blisters (see Fig. 6)	Poor adhesion between top 3-ply asphalt roof & bottom 3-ply coal-tar roof
12	16	Roof damaged by wind storm	Few blisters of surface coating	

TABLE IV - continued

Roof No.	Age Yrs.	By Building Owner	Roof Inspection at Site - 1968	Laboratory Inspection of Cut-Outs
13	11	No leaks	Poor roof design, evidence of deck and insulation movement (see Fig. 7)	Excellent bond between plies, & to insulation
14	9	No leaks	Good appearance	Good bond
15	15	No leaks	Good appearance, Some coal-tar flow	Excellent bond between plies
16	29	Excellent service	Excellent, New coating applied 1967	Excellent bond between plies
17	6	Experimenting with 2-ply system, not entirely successful	Some blisters	Large delaminated areas between plies
18	12	Trouble caused by high humidity within paper mfg. plant. Also 2-ply experiment	Blisters and splits	Some delamination between plies
19	11	Some repair needed, Also 2-ply experiment	Some splits	Some delamination between plies
20	12	Extensive repair, Also 2-ply experiment, Severe leaks	Very poor & troublesome roof, caused by moisture within building.	Some delamination between plies
21	18	No leaks	Numerous blisters	Excellent bond between plies
22	13	No leaks	Extensive blisters	Excellent bond between plies
23	10	Subjected to several hurricanes, No leaks	Coating on south exposure worn off, Some felt torn	Excellent bond between plies
24	15	History of leaks	Roof covered with mineral cap sheet, Few large splits	Splits through complete membrane
25	15	Subjected to several hurricanes, No leaks	Coating worn off, Felts at laps delaminated & torn (see Fig. 8)	Excellent bond between plies

4.3 General Conclusions

1. From the results of the laboratory tests and the observed behavior of 26 roofs in the field, it can be concluded that roofs constructed of 1-ply base sheet and 2-ply #15 asbestos felt; 3-ply #15 asbestos felt; and 4-ply #15 asbestos felt will provide satisfactory service provided that the material meets applicable specifications and the workmanship is in accordance with good roofing practice.

2. The advantages of top coatings on smooth surface asbestos roofs is questionable, with the exception of presenting a uniform appearance. The performance of asbestos roofs did not appear to be affected by the lack of top coatings.

3. Examination of some 40 built-up roof cut-out membranes (in addition to those in this investigation) of all types from many parts of the country indicate that the between-ply moppings of bitumen was generally less than specified by currently promulgated roofing specifications. Stafford and others have come to this same conclusion [2]. This investigation has revealed between-ply spreading rates of as little as 10 pounds per 100 sq. ft. with an average spreading rate of 15 pounds per 100 sq. ft.

5. References

[1] W. C. Cullen, Report on the Performance of Glass Fiber Base Built-Up Roofs, NBS Report 6966 (30 Sept. 1960).

[2] R. M. Stafford, Designing Low Slope Roofing System, The Construction Specifier (May 1968).

[3] W. C. Cullen, T. H. Boone, Thermal-Shock Resistance for Built-Up Membranes, NBS Building Science Series No. 9 (August 1967).

[4] T. H. Boone, L. F. Skoda, W. C. Cullen, Laboratory-Field Comparisons of Built-Up Roofing Membranes, NBS Technical Note 473 (December 1968).

FIGURE 2. Delamination of asbestos felt on smooth built-up roof.

FIGURE 3. Blister caused by poor interply adhesion.

FIGURE 4. Seperated plies of asbestos felt from cut-out of roof, FIGURE 3, showing lack of bond between plies.

FIGURE 5. Cracking of top coating on smooth surface asbestos built-up roof.

FIGURE 6. Large blister caused by incompatability of top asphalt built-up roof with that of bottom coal-tar roof.

FIGURE 7. Eleven year old asbestos roof membrane providing leak-free service despite extreme deck and insulation movements.

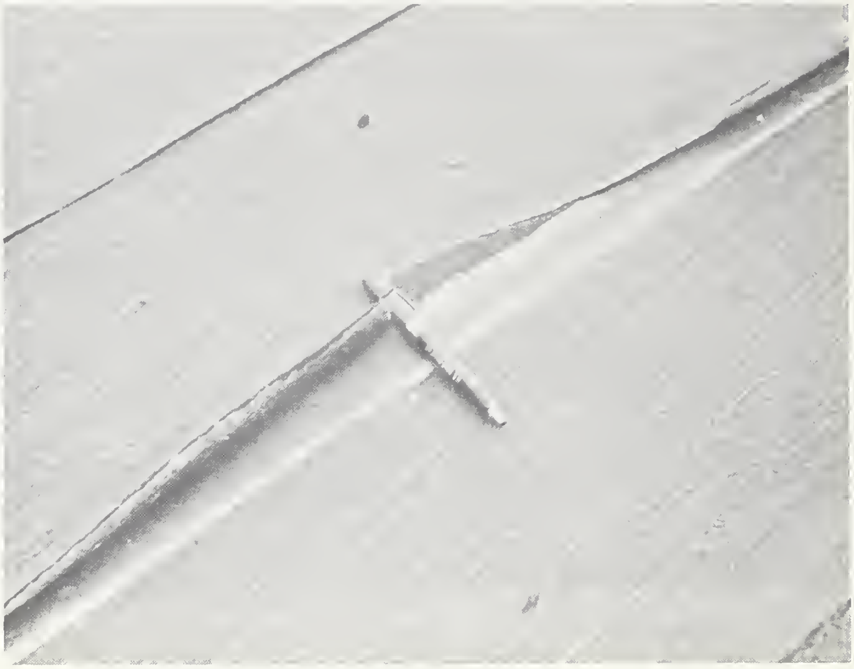
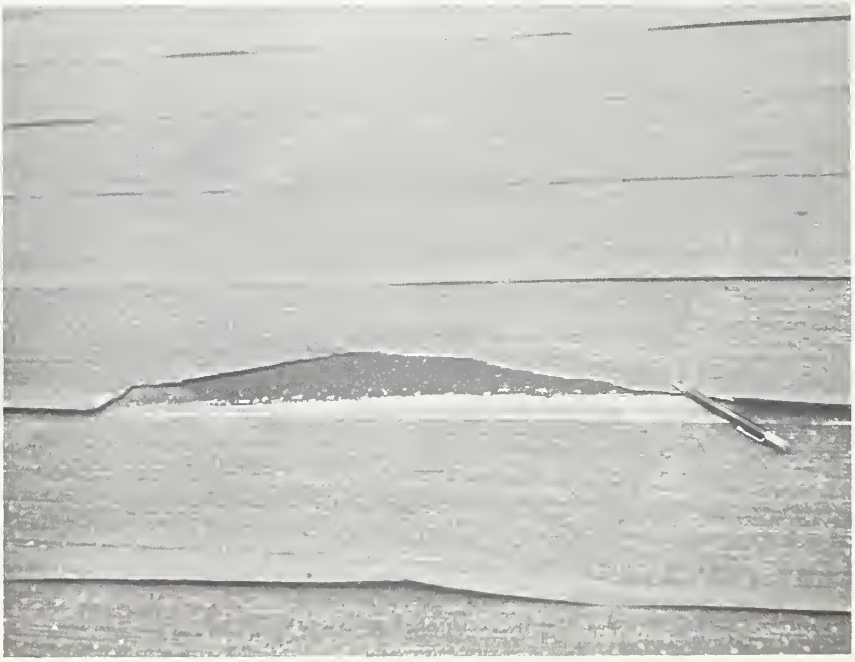


Figure 8. Asbestos felts delaminated and torn. This roof was subjected to several hurricanes.



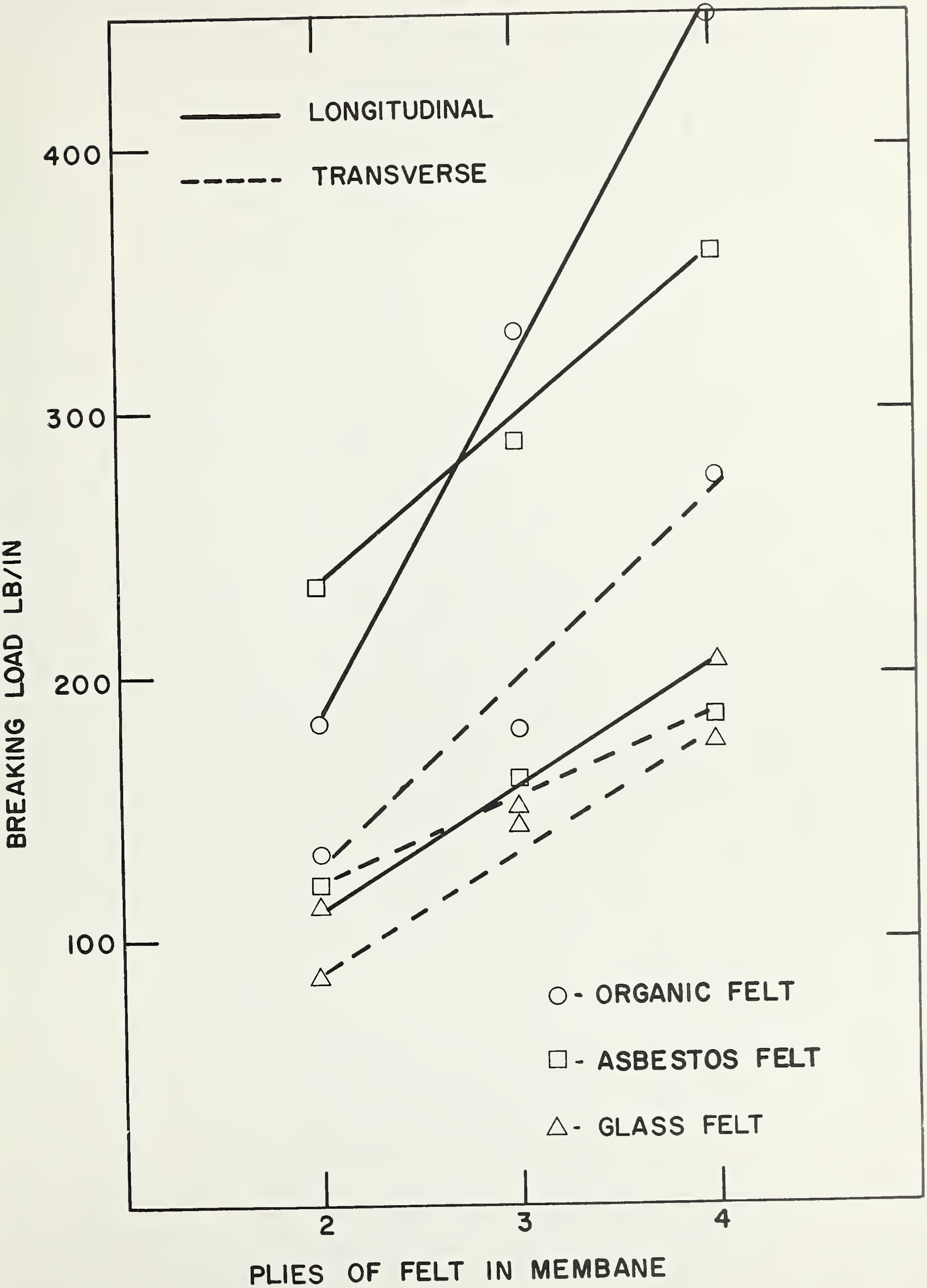
Appendix I

The following table contains partial data obtained from a series of round-robin tests sponsored by ASTM's Committee D-8 Task Force on Method D-146. The table includes only those results pertinent to this investigation which are tensile tests of asphalt saturated organic felts, asphalt saturated asbestos felts and asphalt impregnated glass felts. Each number represents the average of 10 tensile tests. The strengths were determined in accordance with the Standard Methods of Sampling & Testing Felted and Woven Fabrics Saturated with Bituminous Substances for Use in Waterproofing & Roofing, ASTM Designation D-146-65, except for rate of pull. Instead of operating the tester at a constant time-to-break it was operated at a speed of 2-inches per minute. These results were obtained at the NBS Laboratories only and do not reflect results obtained at the other seven participating laboratories.

	Tensile at Break lb/in width	
	Longitudinal	Transverse
Asphalt Saturated Organic Felt, No. 15 type	39	17
Asphalt Saturated Asbestos Felt, No. 15 type	30	14
Asphalt Impregnated Glass Felt, No. 8 type	17	14

Figure a contains comparative tensile test data of roofing membranes constructed of various plies and various kinds of felts. The asbestos felts data was obtained from this series of tests. The organic felt and glass felt data were obtained on other investigations [3] [4]. All data included in Figure a were obtained from field prepared membranes or from existing roofs. Age of membranes was not considered. Figure a shows that the asbestos felt membranes are stronger than glass felt membranes but not as strong as organic felt membranes in every case.

FIGURE a. Breaking load of built-up roofing membranes at 0°F.



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